Search for double degenerate progenitors of supernovae type Ia with SPY* **

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Abstract. We report on a large survey for double degenerate (DD) binaries as potential progenitors of type Ia supernovae with the UVES spectrograph at the ESO VLT (ESO **S**N Ia **P**rogenitor surve**Y** – SPY). About 560 white dwarfs were checked for radial velocity variations until now. Ninety new DDs have been discovered, including short period systems with masses close to the Chandrasekhar mass.

1 The project

Supernovae of type Ia (SN Ia) play an outstanding role for our understanding of galactic evolution and the determination of the extragalactic distance scale. However, the nature of their progenitors is still unknown (e.g. [7]). There is general consensus that the event is due to the thermonuclear explosion of a white dwarf when the Chandrasekhar mass ($1.4 M_{\odot}$) is reached, but the nature of the progenitor system remains unclear. Two main options exists: the merging

* Based on data obtained at the Paranal Observatory of the European Southern Observatory for programs 165.H-0588, 167.D-0407, 266.D-5658, 268.D-5739, 68.D-0483, 69.D-0534

** Based on observations collected at the German-Spanish Astronomical Center, operated by the Max-Planck-Institut für Astronomie Heidelberg jointly with the Spanish National Comission for Astronomy of two WDs in the so called double degenerate (DD) scenario [2], or mass transfer from a red giant/subgiant in the so-called single degenerate (SD) scenario [15].

In the DD case, we know that most stars end up as white dwarf remnants and that a major fraction of stars are in binary systems, hence DDs must be common among WDs. What we do not know is whether there exist enough DDs able to merge in less than one Hubble time and produce a SN Ia event. In the SD case, we know that white dwarfs accreting from a non-degenerate companion do exist, but we do not know whether such systems exist in sufficient number to account for the observed SN Ia frequency, nor whether the WD grows enough to reach the critical mass for ignition. There is also evidence from a class of sub-luminous SN Ia that both routes might be significant [1].

On the theoretical side three possible outcomes of the merger of a super-Chandrasekhar mass DD are discussed in literature: a SN Ia explosion leaving no remnant [2], [13], an accretion induced collapse producing a neutron star without a SN Ia explosion [14], or the formation of a neutron star during a SN Ia event [5]. On the observational side several systematic radial velocity (RV) searches for DDs have been undertaken starting in the mid 1980's checking a total of ≈ 200 white dwarfs RV for variations (cf. [8] and references therein), but have failed to reveal any massive, short-period DD progenitor of SN Ia. This negative result casted some doubt on the DD scenario. However, it is not unexpected, as theoretical simulations suggest that only a few percent of all DDs are potential SN Ia progenitors [3], [12].

In order to perform a definitive test of the DD scenario we have embarked on a large spectroscopic survey of ≥ 1000 white dwarfs (ESO **S**N Ia **P**rogenitor survey**Y** – SPY). SPY will overcome the main limitation of all efforts so far to detect DDs that are plausible SN Ia precursors: the samples of surveyed objects were too small. Spectra were taken with the high-resolution UV-Visual Echelle Spectrograph (UVES) of the UT2 telescope (Kueyen) of the ESO VLT in service mode. Our instrument setup provides nearly complete spectral coverage from 3200 Å to 6650 Å with a resolution $R = 18500$ (0.36 Å at Hα). Due to the nature of the project, two spectra at different, “random” epochs separated by at least one day are observed.

ESO provides a data reduction pipeline for UVES, which formed the basis for our first selection of DD candidates. A careful re-reduction of the spectra is in progress. Differing from previous surveys we use a correlation procedure to determine RV shifts of the observed spectra (cf. [9]). We routinely measure RVs with an accuracy of $\approx 2\,\mathrm{km\,s^{-1}}$ or better, therefore running only a very small risk of missing a merger precursor, which have orbital velocities of $150\,\mathrm{km\,s^{-1}}$ or higher.

2 Results.

We have analyzed spectra of 558 white dwarfs and pre-white dwarfs taken during the first two years of the SPY project and detected 90 new DDs, 13 are double-lined systems (only 6 were known before). Results are summarized in Table 1.

Our observations have already increased the DD sample by a factor of six. After completion, a final sample of ≈200 DDs is expected. SPY is the first RV survey which performs a systematic investigation of both classes of white dwarfs: DAs *and* non-DAs. Previous surveys were restricted to DA white dwarfs, because the sharp NLTE core of Hα allows a very accurate RV determination. This feature is not present in the non-DA (DB, DO) spectra, but the use of several helium-lines enables us to reach a similar accuracy. Our results in Table 1 indicate that the DD frequency among DA and non-DA white dwarfs are similar.

Table 1. Fraction of RV variable stars in the current SPY sample for different spectral classes. WD+dM denotes systems for which a previously unknown cool companion is evident from the red spectra (not included in the DA/non-DA entries).

Spectral type	total	RV variable	detection rate
All DDs	558	90	16%
non-DA (DB,DO,DZ)	72	10	14%
WD+dM	30	14	47%

Follow-up observations of this sample are mandatory to determine periods and white dwarf parameters and find potential SN Ia progenitors among the candidates. Good statistics of a large DD sample will also set stringent constraints on the evolution of close binaries, which will dramatically improve our understanding of this phase of stellar evolution. Starting in 2001 follow-up observations have been carried out with VLT and NTT of ESO as well as with the 3.5 m telescope of the Calar Alto observatory/Spain and the INT [9], [10], [11], [4]). Our sample includes many short period binaries, several with masses closer to the Chandrasekhar limit than any system known before. During our follow-up observations we have detected a very promising potential SN Ia precursor candidate discussed below.

Our follow-up observations concentrated on candidates with high RV variations, indicating short periods. Double-lined systems (with both white dwarfs visible in the spectrum) are of special interest, because these binaries allow the determination of individual masses for both components.

Exemplary for other double-lined systems we discuss here the DA+DA system HE 1414−0848 [11]. The orbital period of $P = 12^{\rm h}25^{\rm m}44^{\rm s}$ and semi-amplitudes of $127\,{\rm km\,s^{-1}}$ and $96\,{\rm km\,s^{-1}}$ are derived for the individual components. RV curves for both components are displayed in Fig. 1. The ratio of velocity amplitudes is directly related to the mass ratio of both components. Additional information comes from the mass dependent gravitational redshift. The difference in gravitational redshift corresponds to the apparent difference of “systemic velocities” of both components, as derived from the RV curves (Fig. 1). Only one set of individual white dwarf masses fulfills the constraints given by both the amplitude ratio and redshift difference (for a given mass-radius relation). We estimate the masses of the individual components with this method to be

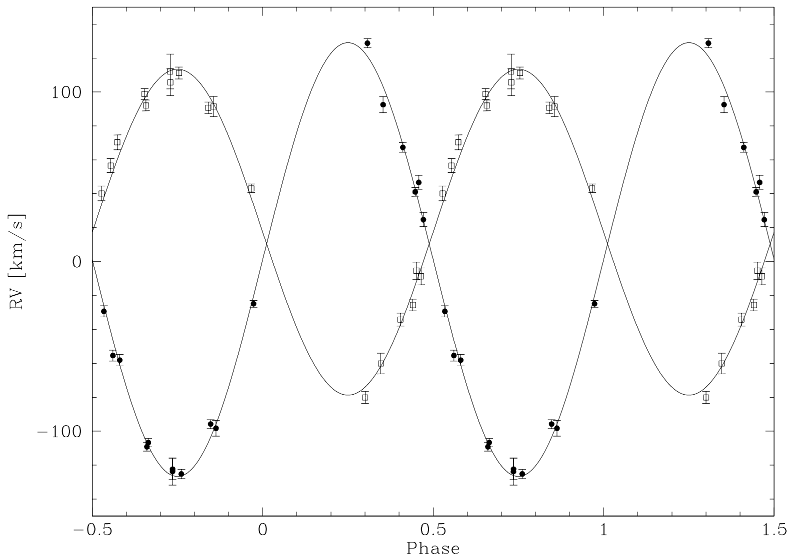

Fig. 1. Measured RVs as a function of orbital phase and fitted sine curves for HE 1414-0848. Filled circles/open rectangles indicate the less/more massive components A and B. Note the difference of the "systemic velocities" γ_0 between both components caused by gravitational redshift.

$0.55 M_\odot$ and $0.71 M_\odot$ for A and B, respectively. This translates into $\log g = 7.92$ and 8.16, respectively.

Another estimate of the white dwarf parameters is available from a model atmosphere analysis of the combined spectrum. We have developed a new tool (FITSB2), which performs a spectral analysis of both components of a double-lined system. The fit is performed on all available spectra, covering different orbital phases simultaneously. We fitted temperatures and gravities of both components of HE 1414−0848 (the mass ratio fixed at the accurate value derived from the RV curve). The results are $T_{\rm eff}/\log g$ = 8380 K/7.83 and 10900 K/8.14 for A and B (Fig. 2), which are in good agreement with the $\log g$ values predicted from the analysis of the RV curve. The total mass of the HE 1414−0848 system is $1.26 M_\odot$, only 10% below the Chandrasekhar limit. The system will merge due to loss of angular momentum via gravitational wave radiation after two Hubble times.

Our follow-up observations yielded parameters for several DDs. We have completed the analysis for three double-lined systems summarized in Table 2. The mass sum of the HE 2209−1444 system is as high as that of HE 1414−0848, but the HE 2209−1444 system is closer and will merge within 4 Gyrs. On the other hand the WD 1349+144 system consists of two low mass white dwarfs and has a rather long period and will merge only after more than 100 Hubble times.

Our sample includes also another short period ($P = 7^{\rm h}12^{\rm min}$) system, which will merge after 4 Gyrs and has probably a system mass above the Chandrasekhar

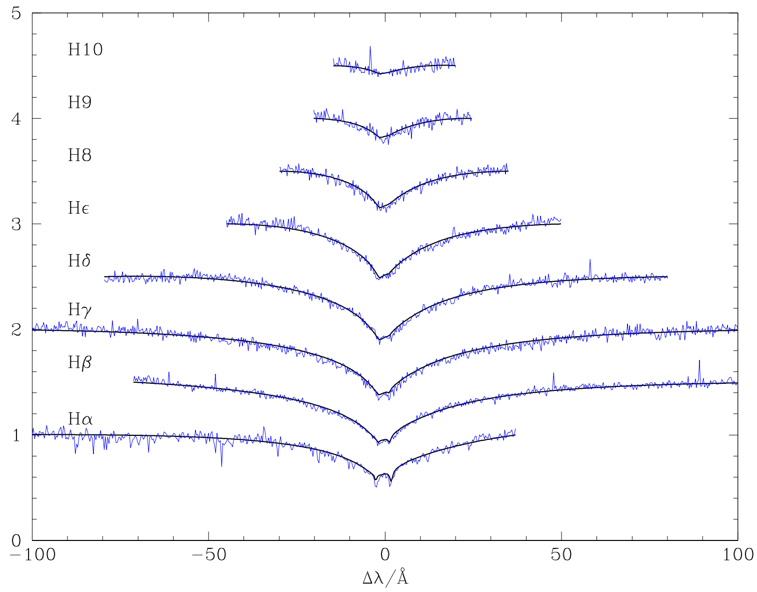

Fig. 2. Model atmosphere fit of the Balmer series of HE 1414−0848 with FITSB2. This is only a sample fit. All available spectra, covering different orbital phases, were used, which allows an unambiguous parameter determination.

Table 2. New double-lined DDs from SPY (data taken from [11] and [4]). The table details the mass sum ($M_1 + M_2$) of the systems, the orbital periods (P), and the time ($T_{\rm merge}$) until merging due to gravitational wave radiation.

system	$M_1 + M_2$ $[M_\odot]$	P h	$T_{\rm merge}$ Gyrs
HE 1414−0848	1.26	12.4	25
HE 2209−1444	1.26	6.6	4
WD 1349+144	0.88	53.0	2000

limit. Thus this system is a very promising potential SN Ia precursor candidate. However, the Hα line core of the secondary in this system is broad and shallow compared to typical DA line cores, which makes the determination of a precise RV curve and therefore of the masses difficult. Some additional data are necessary to verify our RV curve solution. Results will be reported elsewhere.

3 Conclusions

SPY has now finished a major fraction of the survey. Our analysis of the data from the first 24 months has already quadruplicated the number of white dwarfs checked for RV variability (from 200 to 760) and increased the number of known DDs from 18 to 108 compared to the results of the last 20 years. Our sample includes many short period systems (Table 1; [10], [11], [4]), several with masses closer to the Chandrasekhar limit than any system known before, greatly improving the statistics of DDs. We expect this survey to produce a final sample of ≈200 DDs.

This will also provide a census of the final binary configurations, hence an important test for the theory of close binary star evolution after mass and angular momentum losses through winds and common envelope phases, which are very difficult to model. An empirical calibration provides the most promising approach. A large sample of binary white dwarfs covering a wide range in parameter space is the most important ingredient for this task. We have started a project to exploit the information provided in the SPY sample of DDs.

Our ongoing follow-up observations already revealed the existence of three short period systems with masses close to the Chandrasekhar limit, which will merge within 4 Gyrs to two Hubble times. Even if it will finally turn out that the mass of our most promising SN Ia progenitor candidate system is slightly below the Chandrasekher limit, our results already allow a qualitative evaluation of the DD channel. Since the formation of a system slightly below the Chandrasekhar limit is not very different from the formation of a system above this limit, the presence of these three systems alone provides evidence that potential DD progenitors of SN Ia do exist.

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